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February, 1912. Chemical Series. Vol. II, No. 3.

Biological & Medical Serials

Memoirs of the Department of Agriculture in India

STORAGE

THE 'RAB' SYSTEM OF RICE CULTIVATION IN WESTERN INDIA

BY

HAROLD H. MANN, D.SC

Principal, Agricultural College, Poona

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PUBLISHED FOR

THE IMPERIAL DEPARTMENT OF AGRICULTURE IN INDIA

BY

THACKER, SPINK & CO., CALCUTTA
W. THACKER & CO., 2, CREED LANE, LONDON

Price, Re. 1.

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VERY early in the study of agricultural conditions in Western India, attention was called to the peculiar system of preparing the seedbed in which rice is grown for transplanting, which was and is very widespread, indeed almost universal, in the country from the Nerbudda on the north to Kanara in the south. This system consists in burning cowdung, the branches of trees and shrubs, straw, dried grass, or other combustible materials on the ground on which the seed is to be sown, and from which the seedlings are afterwards to be transplanted. This process is called '*rab.*'

By all the agricultural population who grow rice within the limits we have mentioned, this operation is considered of great importance, and many go so far as to say that unless it is done it is impossible to obtain rice seedlings fit to transplant. It is, however, a very troublesome system to work. The cowdung required is very large in amount, and the quantity required precludes its use as a manure in other directions. The branches required have now frequently to be brought from long distances, as the trees which furnish them have often been destroyed in the neighbourhood of the rice tracts, so that a very large amount of trouble is required to get and burn the materials on the rice seedbed. But, in spite of this it

is continued, and very generally continued, in the area indicated until the present day.

In the present account of this process, and the experiments we have made in connection with it, we will divide the subject as follows :—

I. The methods of '*rab*' as at present carried out, with a consideration of analogous processes elsewhere.

II. Historical account of experiments hitherto made to investigate the nature and value of the *rab* system.

III. Details of our own experiments on the subject.

IV. Conclusions and recommendations.

I.

THE METHODS OF *RAB* AS AT PRESENT CARRIED OUT, WITH A CONSIDERATION OF ANALOGOUS PROCESSES ELSEWHERE.*

The actual method of rice cultivation cannot be better described than in the words of a report written in 1853 by H. Day, when engaged in the survey of the Thana district, which is as follows :—†

"The next point, which claims our attention is the system of husbandry pursued in the district, and I need hardly mention that this is almost entirely connected with the rice cultivation. As soon nearly as the rice is off the ground, the lopping of boughs from the trees, the collecting of underwood, leaves, dried grass, cowdung, etc., for the purpose of burning a small portion of land in which the rice plants are to be raised and afterwards planted out in the plots fitted for their reception (the action of fire effecting the destruction of weeds and noxious herbs and at the same time very much increasing the productiveness of the land operating thereto as a manure) are manifestations—I might almost say the only ones—of agricultural activity which are apparent, and these continue with almost unabated diligence from the beginning of December to nearly the end of May."

"To the several holders or rather holdings of rice land there seem to be allotted portions of the jungle in their respective villages from which they may collect fuel for this purpose, but sometimes the entire able-bodied population of a village does not afford sufficient labour for this arduous operation, in which case they appear

* In this and the succeeding sections we have utilised very largely the material collected and published by E. C. Ozanne in 1886 as Bulletin No. 4 of the Bombay Department of Agriculture. We have done this because Ozanne's admirable account has long been out of print and unobtainable.

† We quote from Ozanne's Bulletin

to help one another alternately, the helping and helped villagers reciprocating these good offices."

"The proportion of ground thus scorched or burnt is of course in proportion to the extent of land to which it serves as a nursery as it were; but this is generally about two or three *gunthas*."*

"The art of arranging these combustible materials consists, it appears, in spreading first the cowdung. Upon it are strewed the boughs, grass, etc. Over all is spread a thin coating of earth. The rice is sown in the ashes (the products of this burning) sometimes before the rain falls, and sometimes and more generally after the first fall. In the former case it is termed the *Dhulvaph* and has this advantage that the seed springs before the rain comes, and no time is lost thereby. But as ploughing is needful in both cases to cover the seed, this cannot be carried out where the soil is very hard and deep. It is mostly limited to the neighbourhood of the hills and shallow soils. It has a further advantage, that the rain sometimes comes down with such little intermission, that a considerable period may elapse before sowing and its attendant ploughing can take place, while by the former system the young plant may have arrived at half the maturity necessary for its transplanting before the seed in the latter system has been sown. The land destined for the reception of young plants is prepared thus:—

"Immediately after the first fall of rain it is ploughed three times, the first ploughing being called *Ukhalni*, the second *Dunani*, being at right angles to the first, and the third *Chikhaltas*, so called, I suppose, from the state of the land at the time of the third ploughing when it is usually reduced to a state of mire from continued rain. To break the clods yet more effectually buffaloes are esteemed from their greater bulk as better adapted for this latter ploughing than the ordinary bullock. The *Alvat Phali* answering the purposes of a roller, though not a cylindrical implement, is then drawn over the field, which is now levelled and ready to receive the plant. I have omitted to speak of the *Dantale* or rake, which is used in some cases, I believe, to cover the seed when thrown into the ashes instead of

* A *guntha* is equal to one-fortieth of an acre.

the plough, but in all cases to smooth the surface after the operation (sowing) has been performed. It takes about twenty days from the time of the seed striking to its being fit for transplantation. I believe the plants are all removed from the spot in which they were sown. That portion is then ploughed up in its turn and planted over, like the rest of the rice plots—the rice grown upon it yielding a greater amount of grain, it is said, and the latter preferred and kept for the next year's seed. I have never had an opportunity of seeing these latter operations, and describe them as related to me. The plough used in this district is a very light one and yoked by only two bullocks. From the complete saturation of the earth during the rains and the intense heat of the sun afterwards, it is burnt almost to the condition of brick, and with such ploughs until the rain has again softened the earth it could not be tilled. I believe that the large Deccan plough with eight or ten bullocks could work the soil during the dry season, but the plots of rice are so small that such teams could not turn on them. The consequence is that all the ploughing for the year has to be carried on during the first three weeks in June or during a shorter period even, and *rayats* occupying more than five bighas require not only a corresponding increase of cattle, but of ploughs also to enable them to get through their labour in time.''

This description is a very accurate one. Two or three remarks in connection with it may however be made. The system called '*Dhulvaph*' is not common except on very shallow soils, and the inquiries we have made do not deal with this at all, but only with the far more common method of sowing in the land after the rains have come. The material burnt on the land is not always composed of the mixture of cowdung, boughs, grass, etc., described by Day. Sometimes cowdung only is used ''broken into irregular pieces about one to two inches thick and placed close together to cover the seed-bed.''* In other cases only branches and loppings are used covered with a layer of grass and finally a little earth. In all cases, how-

* Ozanne.

ever, cowdung is preferred as the material, and it is only because the quantity available is rarely or ever sufficient that other materials are employed.

The account which we have cited gives no indication as to the exact time of the year preferred by the people for the burning of the *rab*, but merely indicates that the collection of the materials and their burning on the land is the chief occupation of the people from December to May. There are, however, very strong prejudices on the subject which seem to vary from district to district. In some parts, the general opinion is that it should be done as early as possible, and February and March are spoken of as the best time. In others the burning is left as late as possible consistent with getting it completed before the coming of the South-West monsoon. One thing seems to be generally recognised however. If showers of rain fall between the time at which the *rab* is burnt and the time when the rain is copious enough for it to be ploughed and sown, then the advantage is largely reduced.

We have already indicated in general terms the range of country in which the practice of *rab* is generally carried out. We will quote the words of Ozanne (*loc. cit.*) which represent substantially the present situation.

"Generally speaking, it may be said that *rab* is confined to districts of heavy rainfall (say from eighty to one hundred inches and over). Kanara, however, which has a heavy fall of rain, appears to be an exception. *Rab* again gradually disappears in the North of the Presidency, as the districts of Gujarat proper begin. Rice is extensively grown both in Kanara and in Gujarat and also in districts, *e.g.*, Dharwar, where the rainfall is much lighter, and even is grown on the transplantation system, in which, as in the case of *rab*, the nurseries are well manured. The manure is not burnt. In some of these districts the absence of abundant brushwood may partly account for the absence of *rab*, but this explanation cannot generally hold. Again, *rab* extends over the ridge of the Western Ghats and is prevalent in Poona, Nasik, etc. Another fact bearing on the climatic limits of *rab*

is that while *rab* is universally practised for sweet rice, it is never resorted to in the case of salt marsh rice, *i.e.*, rice grown in reclaimed salt marsh near the coast and on the banks of creeks. This is an inferior variety of rice. In the Poona District at least, where *rab* gradually disappears with the decreased rainfall, it seems to come to an end sooner than the cultivation of rice ; but here again the fine varieties of rice appear to vanish with *rab.*''

'' On the whole, it may be stated with confidence that *rab* is confined to districts of heavy rainfall, though the converse is by no means true to facts.''

This statement is wrong, however, in one particular. The system is not so closely confined to districts of heavy rainfall as Ozanne imagined. It is found in Lower Sind, where the rainfall is almost negligible, and in one or two areas where the rainfall is small. We shall again discuss this supposed connection with heavy rainfall at a later part of the present paper.

As described, the practice of *rab* was for a long time thought to be absolutely unique, but recent discoveries have led to the certainty that many other systems of cultivation must be considered as parallel with that which we are discussing. The extraordinary effect of heating various soils on the growth of succeeding crops has made it appear probable that some at any rate of the effect of the process may be due to the heating of the soil which is involved in it.

But such heating is not uncommon both in and out of India in ordinary agricultural practice. Let us consider the cases arising out of India in the first place. The old method of 'paring and burning' heavy land, not only when pasture was being converted into arable cultivation, but also when it was desired to improve cold clay arable land, may probably be considered as similar in some respects to that which we are discussing. This operation was subjected to a close chemical study by Voelcker in 1857.* In this case the clay was burnt in heaps which were then spread on the land. It was insisted that the operation should be done at a low temperature,

* Journal Royal Agri. Society of England, Vol. XVIII, p. 342.

and as a result the soil was supposed to be sweetened and cleaned, parasites and weeds killed, the mechanical texture improved, and the available mineral plant foods increased. This process has however largely died out in the clay lands of European countries, though what is practically the same thing is commonly and regularly done on a few lands of eastern England.

With the exceptions named, we are not aware of anything analogous to the process now under consideration which has long been in use in temperate countries. As a consequence, however, of recent discoveries,* heating the soil has been frequently recommended as a method to be used in garden and greenhouse cultivation. We are not aware to what extent this seemingly analogous operation has been carried out in actual practice. Certain it is, however, that with the exceptions indicated, there has been no large scale development on the lines which we are discussing.

If we turn to the tropics, however, operations which now seem to be closely analogous exist among even the most primitive as among the more advanced people in many regions. Taking India only, we will refer to four classes of cultivation which seem to bear at least some similarity.

1. The *Jhum* cultivation of north-east India is one of the most striking cases. This system, adopted by almost all the hill tribes in the more sparsely peopled areas, consists in burning the forest or scrub on a specified area and then settling down on this area for a period of from three to seven or more years. The crops, sometimes mixed, sometimes single, are sown in the ashes of the forest or scrub fire, and are maintained year after year until they cease to be as good as is desired. Then the whole settlement is transferred to a new *jhum* on a new area. This is the regular custom in the foot hills of the Eastern Himalaya, in parts of the Naga and Lushai Hills in Assam, and in many other similar regions. Most of the regions indicated have a very heavy rainfall.

* A full bibliography of the literature on the effect of heat on the soil will be found in *Journal of Agricultural Science*, Vols. I, II, III, under papers by Russell and his co-adjutors.

2. In north-east India, wherever large grass plains exist which are devoted to the feeding of cattle, it is the custom of the graziers to set fire, if possible, to the grass when it becomes sufficiently dry after the end of the rainy season. These grass fires spread over large areas of country and often do great damage. They are, however, justified by the graziers because the grass which grows in the following year is always sweeter and gives better feed for their stock than is otherwise the case. With the predominance which large coarse grasses are apt to get in a tropical grass area, it will be easily seen how important it is to make use of every method possible to improve the herbage even during only part of the year.

3. In the Bombay Presidency there is a practice also which is closely analogous, termed '*dalhi*' or '*kumri*' which may be described in the words of a report of 1881 by A. Shewan,* as follows :—

"*Dalhi* is the form of cultivation known as *kumri* in Satara and the Southern Maratha Country. It is practised only in the villages on the extreme *Ghatmatha*, and in these villages only under certain definite and clearly recognised conditions. These conditions are : First, land covered with jungle. Big jungle is not required. Ordinary scrub or even a thick growth of the *karvi* reed is sufficient. Secondly, land on a slope is required both for facility of burning the brushwood, etc., when cut and lying on the ground and of drainage of the heavy rainfall of these regions. Thirdly, a situation more or less sheltered is necessary. If a crop is grown in a position exposed to the fall of the south-west monsoon, the chances are that it will either rot or be washed away altogether. When these conditions co-exist, *dalhi* can be carried on successfully. A slope is cleared, the jungle felled, and, in May when the wood is thoroughly dried, it is burnt. The ground is thus covered with wood-ash, and in this (generally mixed with the soil by digging with a *kudal*—pick) the seed of *Nachni*† is sown after the first burst of rain. In some places both *Nachni* and *Varai*‡ (a still coarser grain

* Quoted from Ozanne (loc. cit.)

† *Eleusine coracana.*

‡ *Panicum miliare.*

than even *Nachni*) are sown in separate patches and no crop is grown on the land in the second year. Further south however it is the invariable custom to grow *nachni* alone the first year and a crop of *varai* the second, while in especially favoured situations a third and a fourth crop of *ghoti** (a very coarse grain) and *karla*† (oil-seed) are raised from the same land. When this has been done, whether one crop or more have been raised, the land must be fallow for a certain period till it has again become covered with vegetation, when the process above described is repeated. The necessary period of fallow varies of course in different situations, but average *dalhi* land will, after having been cultivated for two years, recover itself in seven or eight.''

4. The burning of the land in the Bombay Presidency in the more hilly districts is not confined to the special and peculiar conditions just described. In the Konkan two hill grains, *nachni* or *ragi* and *varai*, are both grown almost exclusively after due treatment of the land absolutely analogous to that of *rab* in rice cultivation.

We are therefore dealing with no isolated phenomenon, but one which is common throughout the tropical and subtropical regions of the world. It has had even its analogy in Japan, where a similar practice was formerly in vogue in rice cultivation. It was, however, prohibited by the Japanese Government a few years ago.‡

* *Panicum miliaceum.*

† *Guizotia abyssinica.*

‡ Ribbentrop, quoted by Ozanne (loc. cit.).

II.

HISTORICAL ACCOUNT OF EXPERIMENTS HITHERTO MADE TO INVESTIGATE THE NATURE AND VALUE OF THE RAB SYSTEM.

As was natural in the then condition of agricultural science, the tendency in Western India, when the *rab* process was first known and described, was to consider that it was without special advantage, that it was carried out as the result of prejudice arising from long use, and that whatever advantage it might have, would be equally well supplied by the use of wood or other ashes in equivalent amount. This was particularly the dominant note in all remarks on the subject when the forest department was first organised. The people considered that the right to take branches and loppings from the forest to provide the burning material was one which was most valuable to them : the forest authorities were opposed to the practice as decidedly damaging to the forest areas, and hence stated again and again, as they were perhaps justified in doing in the existing state of information, that it could serve no conceivable purpose. The Government of Bombay took the same line, and in 1856 stated* "that the practice of manuring the rice lands with wood ashes, which prevails in the Konkan and which demands a most wasteful appropriation of large tracts of hill land for brushwood, may have its origin quite as much in the gratuitous terms on which fuel has hitherto been obtainable as in the absolute necessity for supplying ashes to the soil. No such system of manuring is found in other rice-producing districts of India, and it is possible that its use in the Konkan is attributable to local circumstances of revenue management rather than to peculiarity of soil."

* Government Resolution 1856 quoted by Ozanne (*l. c.*).

This view more or less prevailed until 1880, and there was little or no recognition of the possibility of the process having a real value not obtainable easily by other means. Attempts to restrict the facilities for obtaining materials for *rab* burning led, however, to such protests that it was felt that a close investigation of the whole subject was necessary.

A large number of experiments were initiated in 1880 or 1881* and carried out by the revenue and forest departments. These experiments proved valueless owing to the manner in which they were carried out and the intricacy of the scheme on which they were done. But in 1885 a series of experiments was made under the direction of Mr. Ozanne, which were considered to settle the question of the utility of the process.

The object of these experiments was to "test the comparative value of the various kinds of *rab* which are recognised by the people, and to determine, in some measure, whether, in the interests of forest conservancy, it is safe to insist on the use of materials less valuable to the country than tree loppings and brushwood for *rab*."†

The work was conducted by means of a number of field tests at five centres, two being in the Poona district, one in Nasik—both above the Western Ghats, and two between these mountains and the west coast, one in the Thana and the other in the Kolaba district. The results were very striking and were summarised by Mr. Ozanne as follows:—

"(1) Cowdung *rab* is decidedly superior to all other varieties, and the better the soil and the better the season the more is its superiority exhibited.

(2) Plots without *rab* and unmanured are markedly inferior not only to the plots with *rab* but to manured plots without *rab*.

(3) Manure unburnt is much inferior, as far at any rate as regards the area of transplantation‡ to manure burnt.

* *Vide* Government Letter No. 1370 of March 17th, 1880.

† Ozanne (*l. c.*).

‡ That is to say, the area capable of being transplanted from a given area of seedbed.

(4) That good results are obtained from *rab* made either from leaf or grass.''

In order to determine these results two tests were used. The first was the area of land which could be transplanted from a unit area of seedbed ; the second, the yield of rice per acre of the rice transplanted from seedbeds variously treated. To indicate the apparent value of the *rab* treatment it will be worth while to give some of the figures which Ozanne obtained.

Taking the first test one may say that one acre of seedbed under various treatments would give the following areas of transplanted rice :—

	Station I (Lonavla).	Station II (Khadkala)	Station III (Igatpuri).	Station IV (Karjat).	Station V (Alibag).
	acres.	acres.	acres.	acres.	acres.
(1) With *rab* of cowdung ..	8·1	5·4	6·0	7·6	4·5
(2) With *rab* of *ain** branches ..	5·8	4·4	..	5·3	..
(3) With *rab* of *fangal*† branches ..	6·8	4·1	2·7	5·4	..
(4) With *rab* of leaves ..	4·4	..	..	..	3·3
(5) With *rab* of grass ..	5·5	..	..	..	3·5
(6) With *rab* of leaves & grass ..	..	2·9	4·6	5·1	..
(7) Without *rab*, and manured with cowdung ..	3·0	3·0	..	..	..
(8) Without *rab*, and unmanured ..	..	..	2·3	1·9	3·2

On the average we, therefore, get that land treated with—

(1) Cowdung *rab* will plant 2·4 times as much as an untreated seedbed.

(2) Branches *rab* will plant 2·1 times as much as an untreated seedbed.

(3) Grass or leaves (or both) *rab* will plant 1·7 times as much as an untreated seedbed.

(4) Cowdung without *rab* will plant 1·3 times as much as an untreated seedbed.

These figures are clear, and if we take the second test, namely, the yield of the areas transplanted from the seedlings from these plots, a very similar result is obtained.

The question of the actual value of the *rab* process was thus set at rest, and Ozanne's conclusions have never been seriously disputed since the time they were published. Two matters, however, have remained open. These are (1) the discovery of a substitute for the *rab* process, which shall yield equally good results and will not

* *Terminalia tomentosa.*

† *Pogostemon purpuricaulis.*

demand a large out-of-pocket expense by the cultivator; and (2), the investigation of the real nature of the *rab* process, so as to lead to the discovery of a more efficient and less wasteful method of carrying it out.

For the investigation of these questions, and more especially of the second, field experiments have been carried on in the rice area at Lonavla (Poona) in the years from 1904 to 1910 under the control of Mr. J. B. Knight. His results have cleared up a number of points, and are, when the long period during which they have been conducted is taken into account, of great value. They have shown, specially, the very great difficulty of conducting field experiments of this type. It has, however, become certain—

(1) that the greater part of the beneficial effect of the *rab* treatment may be attributed to the heating of the soil;

(2) that the effect of the ashes of the *rab* materials, though considerable, is of minor importance compared with that above stated;

(3) that results as good as those obtainable with the *rab* treatment could be obtained by manuring with a considerable number of nitrogenous manures, the most effective, at lowest cost, being oil-cake and particularly safflower cake.

Mr. Knight is shortly to issue a paper embodying the results of his five years of experiment, but the above are, we think, the points which become most clearly evident from a perusal of his results, and they represent the present position of the question.

III.

DETAILS OF OUR OWN EXPERIMENTS.

We have now shortly reviewed what has been done previously by others on the unravelling of the reasons for the peculiar treatment which is followed in Western India in the preparation of the seed-bed for rice. It seemed to us, on first considering the subject, that the main point having been made out that the *rab* process was as advantageous as the cultivators claimed it to be, further progress could only be made in understanding the *rationale* of the process by working under conditions of closer control than is possible in field experiments, and where the process can be more completely analysed.

It having been made out that the heating of the soil was a vital factor in the success of the process, the first point was evidently to determine the extent and duration of such heating during the actual *rab* treatment. By the kindness of Mr. Knight we were able to ascertain this at his experimental station at Lonavla during several burnings of cowdung *rab*,—which is acknowledged to be the most effective.

In the soil of a plot duly prepared for burning, a thermometer was placed horizontally, the upper part of the thermometer protruding into a hole dug in the plot. The bulb was half an inch below the surface. This enabled us to ascertain the heat to which, not the most superficial layer, but the greater part of the surface soil is subjected. The thermometer was read after every five minutes, until the temperature had fallen to an extent which forbade the possibility of further influence. The figures obtained were as follows :—

Time after the burning reached the ground above the thermometers.	Temperature ½ inch deep.
7 minutes.	35° C.
12 ,, ...	40° C.
17 ,, ...	59° C.
22 ,, ...	84° C.
27 ,, ...	80° C.
32 ,, ...	92° C.
37 ,, ...	94° C.
45 ,, ...	108° C.
50 ,, ...	110° C.
55 ,, ...	105° C.
61 ,, ...	108° C.
66 ,, ...	110° C.
71 ,, ...	108° C.
76 ,, ...	110° C.
81 ,, ...	108° C.
86 ,, ...	104° C.
91 ,, ...	97° C.
98 ,, ...	94° C.
103 ,, ...	90° C.

A similar test with a thermometer one inch below the surface gave a maximum temperature of 80°C.

This definitely proves that—

(1) the temperature at half an inch below the surface does not exceed 110° C. at any time during the most approved *rab* process;

(2) the temperature at one inch below the surface does not exceed 75° to 80° C. at any time during the most approved *rab* process;

(3) the effective heating does not last more than one and a half to two hours at the most.

It is interesting to compare the time which the burning takes according to these tests with those given by Ozanne.* He found that "grass and leaf *rab* burnt in 45 minutes, *fangal*† *rab* in 1 hour 10 minutes, *ain*‡ *rab* in 1 hour 35 minutes, and cowdung *rab* in 1 hour 25 minutes."

Before proceeding to analyse more closely the cause of the benefit which is gained by the *rab* process one more thing was necessary,—to ascertain more exactly than had hitherto been possible the exact benefit which the process gives on a particular soil. To do this it was necessary to grow the crop under conditions susceptible of more complete control than is possible in field experiments. To effect

* Loc. cit. † *Pogostemon.* ‡ *Terminalia.*

this, earthenware cylinders, sunk in the ground, were used, and as they have proved very efficient and as all subsequent cultivations have been made in them, we may describe here our method of work.

Glazed earthenware drainpipes fifteen inches in internal diameter, flanged at one end and two feet long, apart from the flange, were sunk in the ground to their full depth. In the position in which they were placed this secured that the lower end of the pipe was always in decomposed trap—termed *Murum* in the Deccan,—and thus drainage was secured. They were fixed in this position by filling in outside the cylinders with soil. They were then filled with the soil under consideration, very carefully and layer by layer. About two inches depth of stones (chiefly quartz) were placed at the bottom of the cylinder, and then successive lots of twenty pounds of the selected soil taken from the same heap (having been sieved through a sieve with holes one quarter inch in diameter) were placed in each cylinder. Each lot was pressed gently and evenly down in the cylinder before the next addition. When nearly full, each lot added was reduced to ten pounds, but otherwise the cylinders were filled similarly.

The soil used for nearly all the experiments here recorded was obtained from the rice area at Lonavla, but the experiments themselves were carried out in Poona.

The seeds of the rice selected for the purpose were then sown at the rate of eighty-three per pot. Considerable care was taken that the weight of the seeds selected should be even and the total weight in each case very nearly the same. They were buried half an inch deep, by preference when the soil was naturally in the moist condition required, but if this could not be secured, distilled water was added in the required quantity. In very nearly all cases duplicate cylinders were employed for every test. The following records were always made :—

(1) the speed of germination ;

(2) the relative appearance of the plants at several stages of growth ;

(3) the appearance at the time when each series would normally be transplanted,—at which the plants were pulled up;

(4) the weight and dry weight, at the time of pulling up.

The chief difficulty met with was in the attacks of insects, particularly small tineid caterpillars, and in a few cases white-ants. In both cases the plants attacked were destroyed and the cylinders in which the attack took place rendered useless. In any case, it was always necessary after about ten days of growth to reduce the number of plants in each cylinder to a constant number, generally between seventy and eighty, being the number in the least successful cylinder. Throughout the growth of the plants, the attentions of birds were averted by covering each cylinder with wire netting.

Using cylinders prepared as just described, we were, first, anxious to ascertain clearly how far the useful effect of the *rab* process was due to the heating of the soil and how much to the ashes which were formed during its burning. Eight cylinders were therefore taken in four sets of duplicates.

Nos. 1 and 2 were untreated in any way: to Nos. 3 and 4 the ashes of *rab* material (cowdung and grass) burnt elsewhere were applied. On Nos. 5 and 6 the similar quantity of *rab* material was burnt and then the ashes were scraped carefully from the soil. And finally in Nos. 7 and 8 the full *rab* treatment was applied. Thus we have in—

Nos. 1 & 2	No treatment.
Nos. 3 & 4	Ashes from *rab* material only.
Nos. 5 & 6	Heating of the soil only.
Nos. 7 & 8	Full *rab* treatment.

These were sown at the beginning of July 1908 six weeks after the *rab* materials had been burnt or the treatment made, and remained on the ground unusually long, in fact until September 10th in that year. The seedlings were then pulled up, and a second crop planted.

In the first crop, the plants in each case were carefully examined at four stages during their growth and each plant was valued as first

class, second class, or third class plant on each occasion. The percentage of first class plants in each case was as follows :—

	Untreated.		Ashes only.		Heating only.		Full *rab* treatment.	
Cylinder No.	1	2	3	4	5	6	7	8
	%	%	%	%	%	%	%	%
August 17 ..	18	20	39	37	44	36	58	58
August 27 ..	17	18	39	37	46	44	59	60
September 2 ..	17	18	38	37	47	44	61	60
September 6 ..	17	18	38	38	47	45	61	61
September 10 ..	17	19	38	38	48	45	60	62

These figures would indicate the relative value of the portions of the treatment sufficiently clearly. The actual weight (dried) of the plants reaped on September 10th was as follows :—

	Weights of Plants.		Average.
	1	2	
	grammes.	grammes.	grammes.
Untreated soil	7·3	6·1	6·7
Ashes only	11·3	12·8	12·05
Heating only	(9·3)	(18·3)	(13·8)
Full *rab* treatment	19·8	18·0	18·9

These results agree fairly closely with the former figures obtained from the appearance of the plants, except in the case of those marked ' heating only.' Here the duplicates do not agree, and do not agree with the results of observation. We propose to exclude these results therefore. The others are clear. If we take the crop from untreated soil as unity, we may say that the ashes of the *rab* material increase the crop of seedlings by 80 per cent., while the full *rab* treatment increases it by 182 per cent. Of the total increase due to the *rab* treatment in question, 44 per cent. appears to be due to the ashes, and 56 per cent. to other causes of which the heating of the soil is undoubtedly the most important.

A second crop of rice seedlings was grown on the same cylinders immediately after the first crop had been removed. The results, which we will not at present show in detail, indicate that the effect of the treatment has almost entirely disappeared. The actual

figures for the weight of crop, after growing from September 10th to October 20th, were as follows :—

	Weight of Plants.		Average.
	1	2	
	grammes.	grammes.	grammes.
Untreated soil	(10·5)	(5·5)	(8·0)
Ashes only	9·0	6·5	7·8
Heating only	6·7	7·3	7·0
Full *rab* treatment	6·0	7·5	6·8

The crop was poor and the agreement of the duplicate results is not good enough to enable us to place much weight on the results, but it seems clear that very little remains four months afterward,—the rainy season having intervened—of the value of the various treatments adopted. We shall return to this subject at a later stage.

But if, as seems to be indicated by these preliminary results, a very large part of the beneficial effect of the *rab* process is due to the heating of the soil, it is obvious that this heating may be conducted by other methods than by burning *rab* on the surface. And this affords an opportunity to ascertain the amount of heating which will give the most effective result.

Taking, therefore, the temperature and length of heating obtained in practice as a basis, sixteen cylinders were set out in which the surface soil to a depth of approximately one inch was heated to various temperatures, as follows, in each case exactly six weeks before the planting of the seed.

1 & 2	.. No heating.
3 & 4	.. Heated to 50° C. for 1 hour.
5 & 6	.. Heated to 75° C. for ½ hour.
7 & 8	.. Heated to 75° C. for 1 hour.
9 & 10	.. Heated to 100° C. for ½ hour.
11 & 12	.. Heated to 100° C. for 1 hour.
13 & 14	.. Heated to 125° C. for ½ hour.
15 & 16	.. Heated to 150° C. for ½ hour.

The surface soil was heated in an oven, to the necessary temperature and for the time indicated, six weeks before it was intended to plant the seed, and was then put into the cylinders previously filled for the remainder of their depth with ordinary soil of the same kind. The seed was sown on June 10th, and observations of

each plant made on six separate occasions during their growth, which was allowed to continue until August 19th, when the seedlings were pulled up, dried and weighed. They were then much bigger than would be required for transplanting, but the conclusions are almost certainly quite similar to those which would have been obtained earlier. The duplicate cylinders agree closely in each series of observations made, except with Nos. 13 and 14. Nos. 10 and 16 were damaged with insects, and are hence excluded from the results. In other cases average figures are given of the percentage of first class plants in each pair of cylinders on the five separate dates when observations were made.

Cylinder Numbers.	Treatment.	Percentage of First Class Plants.				
		June 26	July 5	July 15	July 25	August 4
Nos. 1 & 2 ..	Untreated	33	32	38	37	34
Nos. 3 & 4 ..	50° C. for 1 hour	34	42	42	43	28
Nos. 5 & 6 ..	75° C. for ½ hour	33	42	42	42	36
Nos. 7 & 8 ..	75° C. for 1 hour	37	46	46	47	37
No. 9	100° C. for ½ hour	48	47	47	46	33
Nos. 11 & 12 ..	100° C. for 1 hour	41	50	51	50	50
No. 13 ..	125° C. for ½ hour	45	50	50	50	54
No. 14 ..		25	36	36	40	52
No. 15	150° C. for ½ hour	39	46	45	46	64

It is probable that the figures for July 25 most nearly represent the condition of the plants when they should have been transplanted, but by an accident they were not pulled up until August 19th, when they were dried and weighed. At that date the weights were as follows :—

Treatment.	Weights of Plants (dry matter).		
	a.	b.	Average.
	grammes.	grammes.	grammes.
Untreated	25·2	25·3	25·2
50° C. for 1 hour	32·4	30·0	31·2
75° C. for ½ hour	30·0	34·9	32·4
75° C. for 1 hour	31·8	33·8	32·8
100° C. for ½ hour	34·3	....	(34·3)
100° C. for 1 hour	36·0	34·8	35·4
125° C. for ½ hour	39·4	33·4	36·4
150° C. for ½ hour	33·1	....	(33·1)

The results thus obtained are striking. Whether we judge by the character of the plants during their growth as judged by observation, or by the actual weight of dry matter produced it is clear that as the heat previously applied to the soil becomes greater, so the crop obtained improves. As judged by the final crop, the increase is a gradual one and is almost proportional to the amount of heat applied, if we eliminate the highest temperature. If we use the other test, and judge by observation of the plants, the indication is that for the first six weeks of growth, the character of the plants improves as the amount of heating becomes greater up to the point where the soil has been heated to 100° C. for one hour. Beyond this, the results are not equally good, but the same relationship persists in every case up to this point. After this stage of growth, however, the more highly heated soils seem to give even better returns in the appearance of the plants.

We have been able in this case to increase the yield of dried seedlings from 25·2 to 36·4 grammes or by 44½ per cent. This, it is obvious, is not nearly the amount that is produced by the complete '*rab*' process amounting to (in our experiment previously recorded 182 per cent.) but it shows that the heating of the soil is a factor, though not the only factor in the value of the process.

In order to ascertain where the difference between the field results and our figures lay, it was suggested that it was possible that the conditions under which our soil was heated might not have been the best. We heated the soil six weeks before the sowing of the seed. It might be that this was too long or too short a period to achieve the best results. This was rendered more likely because of observations on the heated soil itself of which we shall speak later, pp. 185 & 186.

It was, therefore, decided (1910) to set out a sufficient number of cylinders to allow the growth of rice seedlings in soil heated respectively three months, six weeks, and immediately before the sowing of the crop. Only three temperatures were taken, *namely*—

(1) 75° C. for 1 hour.
(2) 100° C. for ½ hour.
(3) 125° C. for ½ hour.

and thus we had in each case three pairs of duplicate pots in which the soil had been heated three months, six weeks previously and immediately before the sowing. The methods of heating and sowing were identical with those already described. The plants in two cases were unfortunately attacked by insects and had to be neglected.

The heating of the soil was done respectively on (1) 3rd April, (2) 6th May, (3) 6th June in the three sets. After planting on June 13th, 1910, careful observation of each plant was made on July 3rd, July 13th, and July 20th, and the plants were pulled up and dried on August 3rd. The method of conducting this observation was a little different from that previously adopted. The best plants in the whole experiment were given the number "3" in each case. Worthless plants were given the number "0". Intermediate plants received intermediate numbers according to their grade. So that by adding up the whole of the numbers for each in each cylinder, the quality of the plants in that cylinder relative to the quality in other cylinders was at once obtained. So carried out we have a very delicate test of the progress of plants in such cultures as those we are discussing.

The actual figures for those valuations are given in the following table. Only average figures are given as they were in fair agreement among themselves. There were seventy-seven plants in each cylinder :—

Treatment.	Valuation of Plants.		
	July 3	July 13	July 20
No treatment	172	166	165
75° *C. for* 1 *hour.*			
(1) 3 months before	167	179	173
(2) 6 weeks before	177	182	177
(3) immediately before	170	166	177
100° *C. for* ½ *hour.*			
(1) 3 months before	172	180	179
(2) 6 weeks before	195	185	189
(3) immediately before	191	186	185
125° *C. for* ½ *hour.*			
(1) 3 months before	184	187	183
(2) 6 weeks before	175	180	185
(3) immediately before	198	190	195

The plants were pulled out and dried on August 3rd, and the weights obtained showed the following results :—

Treatment.	Weight of Dried Plants.		
	(1)	(2)	Average.
	grammes.	grammes.	grammes.
No treatment*	....	....	5.0
75° C. for 1 hour.			
(1) 3 months before	5.0	4.2	4.6
(2) 6 weeks before	6.2	....	(6.2)
(3) immediately before	5.2	....	(5.2)
100° C. for ½ hour.			
(1) 3 months before	5.5	5.2	5.3
(2) 6 weeks before	8.0	8.5	8.2
(3) immediately before	7.5	7.2	7.3
125° C. for ½ hour.			
(1) 3 months before	6.5	6.5	6.5
(2) 6 weeks before	6.5	5.5	6.0
(3) immediately before	8.2	11.2	9.7

These results, though not absolutely consistent in all details, are, on the whole, sufficiently clear. In the first place, it may be said that the higher the temperature of heating (up to 125°C.) the greater is the *immediate* effect. In this case we got an increase in crop amounting to 94 per cent. (average) which approaches the effect of the *rab* material if we remove the ashes (see page 159). The immediate effect of heating to 100° C. (½ hour) was marked (46 per cent.) but distinctly inferior to that produced by heating to 125°C., —while the effect of heating to 75° C. was very small indeed.

Heating six weeks before the sowing of the crop has apparently a somewhat different effect. Here the highest temperature gave poor results,—a result which is quite inexplicable at present,—while the best return was obtained with the soil heated to 100° C. where an increased return of 64 per cent. was obtained. As before, heating to 75° C. had little effect.

Where the soil was heated three months before, the effect had in all cases almost entirely passed off. In the case of the highest temperature a small increase was still visible (30 per cent.), but in the others, no effect whatever remained.

* There were actually five duplicate cylinders in this case giving respectively (1) 4.5, (2) 5.2, (3) 5.5, (4) 4.8, (5) 5.2 grammes.

These results are very interesting, and—with the exception of the result of heating the soil to 125° C. six weeks before the crop was sown—very clear. This apparent exception will be investigated later. In summary, in fact, we may say—

(1) the effect of heating (at the temperatures we used, and when perfectly dry weather lasted till a week before sowing) passed off almost entirely before three months after heating ;

(2) the result of heating to 75° C. only was very slight indeed at any time ;

(3) the greatest effect of all was produced at the highest temperature used (125° C.) when the heating had been conducted immediately before the sowing of the crop ;

(4) the point of greatest effect of heating lies between 125° C. and 150° C.

A second crop of rice was planted in these cylinders immediately after the removal of the first, without any further treatment. The soil had, therefore, in every case, borne a crop of seedlings,—and had been heated six weeks, three months, and four and a half months before sowing respectively. The last six weeks before sowing the soil had been wet. The results were, however, wholly irregular,—and the only thing which was quite clear was that the effect of heating had entirely passed off as a predominating factor, and that other causes such as the amount of crop previously taken off—completely masked it.

We may, therefore, add one more conclusion to those previously drawn, namely.—

(5) when the soil is wet and bears a crop of rice, the effect of heating passed off, as a predominating factor, in six weeks or less.

This is curiously in accordance with the popular belief that an April or May shower destroys the efficiency of the *rab* treatment on lands which have already been burned.

We have, therefore, now reached a point when we have succeeded by mere heating of the soil in producing an effect comparable with that of the *rab* treatment, if that of the ashes be excluded. To obtain this requires the heating of the dry soil to 125° C., and the immediate or early sowing of the rice on the land.

At this stage it will be well to consider at what part in the life of the plant the beneficial effect of heating occurs. It was stated by Pickering* that the extracts from his heated soils were always unfavourable for germination, and had a tendency to retard it. We have found sometimes an apparently similar effect in our experiments, and, certainly, on the other hand, have never seen that germination was hastened in any way. Thus, for instance, in one of the series of cultural experiments here recorded, observations were made from day to day after sowing as to the number of plants which had appeared above the ground, with the following results. The seeds were sown on June 13th, 1909.

Treatment.	Percentage of Plants above Ground.				
	June 18	June 20	June 21	June 23	June 25
	%	%	%	%	%
Untreated ..	32	79	89	91	96
75° C. for 1 hour	27	66	80	85	90
100° C. for ½ hour	19	61	84	89	96
125° C. for ½ hour	12	58	79	85	92

This seems clear enough, but it was necessary also to germinate seeds watered with extracts of heated and unheated soils. In this case we obtained the following results. The seeds were sown on September 6th.

Treatment of soil.	Percentage of seeds germinated.		
	September 8	September 9	September 10.
	%	%	%
Unheated soil with water extract of soil heated to 75° C. for 1 hour ..	40	80	95
Unheated soil with water extract of soil heated to 100° C. for ½ hour ..	40	85	100
Unheated soil with water extract of soil heated to 125° C. for ½ hour ..	40	80	100
Heated soil to 75° C. for 1 hour with water extract of unheated soil ..	40	80	90
Heated soil to 100° C. for ½ hour with water extract of unheated soil ..	40	80	100
Heated soil to 125° C. for ½ hour with water extract of unheated soil ..	40	70	95

* Journal of Agricultural Science, Vol. II, page 411.

These figures clearly suggest that the germination is slightly retarded by the previous heating of the soil. Further tests, however, seemed necessary and were made in the laboratory under more closely defined conditions, as follows :—

Rice seeds, twenty to each dish, were sown in *Petri* dishes filled with soil either heated or unheated as the case might be, and watered as indicated in the following table :—

A. Unheated Soil, watered with water extract of soil heated to 75° C. for 1 hour.

B. Unheated Soil, watered with water extract of soil heated to 100° C. for $\frac{1}{2}$ hour.

C. Unheated Soil, watered with water extract of soil heated to 125° C. for $\frac{1}{2}$ hour.

D. Heated Soil, to 75° C. for 1 hour, watered with water extract of unheated soil.

E. Heated Soil, to 100° C. for $\frac{1}{2}$ hour, watered with water extract of unheated soil.

F. Heated Soil, to 125° C. for $\frac{1}{2}$ hour, watered with water extract of unheated soil.

Four such experiments were made with results as follows :—

Experiment I.

	Percentage of Seed Germinated.		
	2½ days after sowing.	3½ days after sowing.	5½ days after sowing.
A	35	65	100
B	40	70	95
C	30	70	95
D	35	45	90
E	30	65	90
F	35	55	85

Experiment II.

	Percentage of Seeds Germinated.		
	2 days after sowing.	3 days after sowing.	4 days after sowing.
A	55	75	85
B	50	80	90
C	65	75	100
D	45	80	95
E	60	90	100
F	70	90	100

Experiment III.

	Percentage of Seeds Germinated.		
	2 days after sowing.	3 days after sowing.	4 days after sowing.
A	40	80	95
B	40	85	100
C	40	80	100
D	40	80	90
E	40	80	100
F	40	70	95

Experiment IV.

	Percentage of Seeds Germinated.		
	2 days after sowing.	3 days after sowing.	4 days after sowing.
A	60	90	100
B	65	85	100
C	55	90	100
D	65	90	100
E	65	95	95
F	70	90	100

These results indicate most clearly that under the conditions of experiment there is no difference in the speed of germination of rice seed sprouted in heated and in unheated soils, even if the former have been raised to a temperature of 125°C for half an hour. The effect of the extracts of heated soils on the germination is equally negligible.

The last quoted experiments thus seem to be in contradiction with the former ones, which indicated that while heating to 125°C. or even to 150°C. has a retarding effect on the speed of germination of rice seed when the seeds are sown in it, there is no apparent similar result when the seeds are watered with extract of such soils. In the latter case there is no retarding, and no beneficial action.

We are inclined to think that the retarding effect of the heating when the soils are under field or pot conditions, may be due to the fact that the drainage is better and the seeds do not so easily absorb the moisture which they require for germination. There seems certainly nothing to indicate the production, during heating, of any substance which, directly, injuriously affects or even retards the germination process.

What is, however, the nature of the heating effect on the soil ? On the solution of this question depends very largely the possibility of devising a substitute for the present wasteful process.

The discussion of the question of the effect of heating soil on its fertility has been very keen during the last four or five years, and, for a historical review of the subject, we must refer to the writings of Russell and his co-adjutors. But it may be said that there are three aspects from which the effect can be viewed. These are as follows :—

(1) The increased fertility may be caused by an increase in the available mineral plant food in the soil. This was the view taken long ago by Voelcker after his investigation of the process of ' paring and burning ' in England. It has recently been revived by Pickering ;

(2) the increased fertility may be caused by a change in the physical texture of the soil. This change is extremely marked in the case of soils—all of which are very clayey—which have undergone the *rab* process. This was noticed by Ozanne, and is always remarked upon by the cultivators who use the process;

(3) the increased fertility may be caused by a change in the living organisms in the soil. This is the view taken by Russell and his co-adjutors, whose most recent view is that certain protozoa which prey on the valuable bacteria in the soil are thereby killed, and so allow the bacteria a much freer growth.

It is possible that at any rate the two last mentioned causes are operative in the present case. Our investigations on these points are not, by any means, completed, but we will now present the tentative conclusions to which we have come, and the data on which they are based.

We first took up the study of the actual effect, on the available mineral matter in the soil, of heating such as that which takes place in a field to which the *rab* process has been applied.

It was quickly obvious that by whatever method the available mineral matter was determined, this had been very considerably increased by dry heating of the airdry soil in an oven. In the first set of experiments (conducted with soil from Lonavla similar to that on which the cultivation experiments had been made) the soil was heated to various temperatures and then after cooling was extracted with water, and the extract filtered as rapidly as was possible. The more heated samples were much more easy to filter than the others.

The actual percentage of extract,—and of mineral matter, of organic matter and combined water, and of nitrogen in that extract,—are respectively shown in the following table. The figures for "organic matter and combined water" were obtained by ignition of the extract obtained, already dried at 100° C. All are calculated as percentages of the soil used in each case.

Treatment of soil.	Total water extract.	Analysis of Extract.		
		Mineral matter.	Organic matter and combined water.	Nitrogen.
	%	%	%	%
No treatment	·050	·028	·022	·0024
Heated to 50° C. for 1 hour ..	·052	·029	·023	·0026
Heated to 75° C. for ½ hour ..	·053	·029	·024	·0030
Heated to 75° C. for 1 hour ..	·056	·031	·025	·0032
Heated to 100° C. for ½ hour ..	·059	·032	·027	·0033
Heated to 100° C. for 1 hour ..	·070	·032	·038	....
Heated to 125° C. for ½ hour ..	·096	·042	·054	·0036
Heated to 150° C. for ½ hour ..	·130	·056	·074	·0044

There is, therefore, a constant increase in the amount of matter soluble in water as the soil is heated to a greater extent. This can very well be shown by percentages of increase as in the following table. The extract of the untreated soil is taken as the basis of calculation.

Treatment of soil.	Percentage of Increase.			
	Total extract.	Mineral matter in extract.	Organic matter in extract.	Nitrogen in extract.
	%	%	%	%
Heated to—				
(1) 50° C. for 1 hour ..	4	3·5	4·5	8·5
(2) 75° C. for ½ hour ..	6	3·5	9	25
(3) 75° C. for 1 hour ..	12	10·5	14	33
(4) 100° C. for ½ hour ..	18	14	23	40
(5) 100° C. for 1 hour ..	40	14	73	..
(6) 125° C. for ½ hour ..	92	50	145	50
(7) 150° C. for ½ hour ..	160	100	236	83

The water-soluble matter in the soil has therefore been increased (by merely remaining in an oven in the dry state for a limited time at the temperature stated) by amounts which the above tables indicate. The greatest increase is in the "organic matter and combined water." The proportionate increase in the other constituents determined is not very widely different among themselves.

It may be incidentally noticed that the lime and magnesia, soluble in water, in the untreated soil gave figures as follows :—

Lime (CaO) .. .. ·016 %
Magnesia (MgO) .. .. ·0027 %

A very similar increase is noticed in some constituents of the mineral matter if, instead of determining the water soluble matter, the material soluble in one per cent. citric acid solution is used, by Dyer's method. In this case soil heated to 100° C. for $\frac{1}{2}$ hour, and that heated to 125° C. for $\frac{1}{2}$ hour only were used. Under these circumstances the following figures were obtained :—

	Untreated soil.	Soil heated to 100° C. ($\frac{1}{2}$ hour).	Soil heated to 125° C. ($\frac{1}{2}$ hour).
Alumina and Oxide of Iron (Fe_2O_3) ..	·800	·813	·813
Lime	·224	·208	·208
Magnesia	·017	·019	·019
Potash (K_2O)	·027	·030	·033
Phosphoric Acid (P_2O_5)	·0085	·0091	·0098

By this test, therefore, the soluble Alumina and Oxide of Iron, and Magnesia are increased to only a very slight extent, while the soluble Lime is actually diminished. The soluble Potash at the highest temperature increases on the other hand, by about 22 per cent., and the Phosphoric Acid by nearly 17 per cent.

A cultivation test was now made, in which rice was grown in parallel series of cylinders. In series I. the soil was unheated throughout, but was watered immediately after the planting with the water extract from heated soils. In series II. the soils had been heated and were watered with water extract from unheated soil at the same time as the waterings with extract were given in series I. We thus had—

Series I.	Series II.
A. Unheated soil watered with water. ..	A. Soil heated to 75° C. and water only.
B. Unheated soil watered with extract from soil heated to 75° C. (1 hour).	B. Soil heated to 75° C., watered with extract from unheated soil.
C. Unheated soil watered with extract from soil heated to 100° C. ($\frac{1}{2}$ hour).	C. Soil heated to 100° C., watered with extract from unheated soil.
D. Unheated soil watered with extract from soil heated to 125° C. ($\frac{1}{2}$ hour).	D. Soil heated to 125° C., watered with extract from unheated soil.

The crop (dry matter) obtained after six weeks' growth was as follows :—

	Series I. Grammes.		Series II. Grammes.
A.	6·0	..	8·0
B.	6·1	..	8·6

	Series I. Grammes.		Series II Grammes.
C.	5·8	—	(6·1)
D.	6·0	—	9·0

Taking series I, first, it is evident that the watering with extract from heated soils has had no effect whatever. The weights obtained are absolutely the same when the unheated soil is watered, with pure water and with extract from any of these soils. The heated soil extract, in fact, seems to contain nothing either materially helpful or materially injurious to the rice seedlings.

Series II are interesting. We are afraid that C. (obtained by watering soil heated to 100°C. with extract from unheated soil) is not at present explainable, and further experiments will be made to clear up this point. But taking the others, there is not nearly the same increase in the weight of plants obtained from the more highly heated soil, as we have been accustomed to expect, but there is a much greater increase by heating to 75° C. than has been the case in other experiments. This point demands further experiment, but whatever result there may be in this second series seems to depend on biological rather than chemical factors. We hope to experiment further in this direction.

It seems clear, however, from series I that the water extract from the heated soils had no advantageous effect, in spite of its containing more soluble matter. And this would appear to show clearly that any advantage so derived can only have a very minor part in the effect obtained by heating the soil.

We may pass on, therefore, to consider the part which changes in the physical texture of the soil take in the effect we are considering. As already noticed, the result of the *rab* process on the physical texture of the soil is most marked. This was noticed by Ozanne* and it is one of the points most frequently noticed, in conversation, by the cultivators themselves. For a rice seedbed a good tilth is required. There is little time after the rain comes to secure this good tilth, and the *rab* process enables it to be obtained much more quick-

* Loc. cit. Page 10.

ly than would otherwise be the case. This only applies to the seed-bed. The transplanted land is always ploughed in mud, and hence no question of tilth arises.

That there is a very considerable change in the physical condition of the soil after heating was quickly evident. If unheated soil and soil heated to 125° C., respectively, be shaken up with distilled water in two cylinders, and allowed to settle, the heated soil will settle, leaving the water completely or nearly clear in about two hours. The water containing the unheated soil will remain very turbid for two days or so. This is the case with soils from the *rab* area whether from the Deccan or the Konkan. It simply means that the gelatinous or viscid materials in the soil have largely lost this property, or in other words the soils have become less sticky.

Another test shows the same thing. During our cultivation experiments, it was often necessary to water the cylinders in which the crops were growing. The same volume of water was added to each, but it took a different length of time to sink into the soil in each case. The actual figures noticed in the cylinders where rice was sown immediately after heating the soil are shown in the attached table.

Treatment.	Length of time for 500 c.c. water to disappear in cylinder 15″ diameter.		
	1	2	Average.
Unheated	100 seconds.	105 seconds.	103 seconds.
Heated to 75° C. for 1 hour ..	95 seconds.	100 seconds.	98 seconds.
Heated to 100° C. for ½ hour ..	90 seconds.	95 seconds.	93 seconds.
Heated to 125° C. for ½ hour ..	90 seconds.	90 seconds.	90 seconds.

In every case the water sank in more slowly in the cylinders containing unheated soil, but those with soil heated to 75° C. were very little changed by the treatment.

These differences were noticed immediately the seed was sown, and about a week after the soil had been heated. It was quite marked also on soil which had been heated six weeks or even three months before. When the soils had been exposed to the rainy season for six weeks or so the speed with which the water sank into the soil

was much less, but the difference between the heated and unheated cylinders was still more marked. The following table shows the figures for the same cylinders as in the last table under the same conditions on July 28th, or six weeks later :—

Treatment.	Length of time for 500 c.c. water to disappear in cylinder 15″ diameter.					
	1		2		Average.	
	Min.	Secs.	Min.	Secs.	Min.	Secs.
Unheated	7	30	7	30	7	30
Heated to 75° C. for 1 hour ..	7	0	(7	0)	7	0
Heated to 100° C. for ½ hour ..	6	0	6	0	6	0
Heated to 125° C. for ½ hour ..	4	30	4	30	4	30

It was next necessary to devise a method of investigating this effect on the physical texture of the soil, and after many experiments the following method was adopted.

Fifty grammes of the air-dry soil is shaken up in a 250 c.c. cylinder with 250 c.c. distilled water from which the air has been boiled off and the water allowed to cool. This shaking goes on for 15 minutes and then the cylinder is allowed to stand until the water in the cylinder is transparent enough to read type through it, half way from the surface to the bottom of the cylinder. The time required for the soil to settle so far as to allow this is taken, and becomes the measure of the amount of viscid gelatinous sticky matter in the soil. The figure has no absolute value, but if two such cylinders are prepared and shaken side by side, the figures for the time can be shown to be a fairly accurate measure of the relative amount of viscid material in the soil.

We have done many experiments with this method, and have tested its reliability and the conditions under which it is applicable under many different conditions, most of which we intend to describe in a separate paper. At present, we are only concerned to indicate the results which affect the question of the alterations in the physical texture of land as the result of heating.

As an example of its applicability we may quote the following figures. Samples of soil which had been recently heated were shaken in cylinders as described above. The following table indicates the

length of time required for settling half way down the cylinder, and also shows the amount of matter, capable of being precipitated with alum, left in the liquid at this point in each case :—

Treatment of soil.	Time required for settling.		Weight of precipitable matter in 100 c.c. of liquid.
	Hours.	Minutes.	Grammes.
Unheated	45	35	·0286
Heated to 75° C. for 1 hour ..	42	45	·0216
Heated to 100° C. for ½ hour ..	6	25	·0146
Heated to 100° C. for 1 hour ..	6	10	·0116
Heated to 125° C. for ½ hour ..	3	5	·0020

The change induced in the soil by the heating has therefore been very marked. It is only slightly effective when the temperature has not exceeded 75° C. for 1 hour,—but after heating to 100° C. the length of time required for settling is about one-seventh of that in the unheated soil,—while after heating for half an hour to 125° C. the time required for settling has been reduced to one-fifteenth of what it was before.

Another experiment on the same lines gave the following results, which indicate in a measure the degree of accuracy obtainable by the method. The soil was the same as before but taken on a different date.

Treatment of soil.	Time required for settling.		Weight of precipitable matter in 100 c.c. liquid.
	Hours.	Minutes.	Grammes.
Unheated ..	45	30	·0256
Heated to 100° C. for ½ hour ..	6	15	·0136
Heated to 100° C. for 1 hour ..	5	55	·0106
Heated to 125° C. for ½ hour ..	2	55	·0014

Another kind of test indicates the same point. A series of determinations of the amount of suspended matter in the liquid in the 500 c.c. cylinders already described, at a point half way down the liquid in the cylinders gave the following results. The determinations were made 1 hour, 3 hours, and 24 hours after the shaking of the soil and water took place.

Treatment of soil.	Weight of suspended matter per 100 c.c.		
	a. After 1 hour.	b. After 3 hours.	c. After 24 hours.
	Grammes.	Grammes.	Grammes.
Unheated	·114	·040	·004
Heated to 75° C. for 1 hour ..	·104	·040	·004
Heated to 75° C. for 4 hours ..	·074	·036	·012 (?)
Heated to 100° C. for ½ hour ..	·060	·028	·002
Heated to 125° C. for ½ hour ..	·026	·016	·002

The possible importance of this result was at once manifest. It is universally recognised that a rice seedbed *must* be well and easily drained. It is also curious to find that the area in which the *rab* process is used for rice in India very closely corresponds with the area of soils which naturally contain much sticky material,—chiefly, but not entirely, the very basic soils derived from the trap rocks. We have in fact a process which reduces the stickiness of such soils and which makes them much more easily drained—and the application of the process is largely, though not entirely, limited to the areas where such sticky soils predominate.

The same method was now applied to the study of such soil at various periods after heating, the soil having been kept in the meantime in a bottle in the air-dry condition. The rapid changes which take place in the settling power are remarkable. It may at once be said that the effect had entirely disappeared in the soil kept thus for three months, the results being then entirely irregular. Immediately after heating, and six weeks later (the settling experiments being conducted at the same time) the soils required the following lengths of time to settle: –

Treatment of soil.	Time required for settling.			
	a. Immediately after heating.		b. Six weeks after heating	
	Hours.	Minutes.	Hours.	Minutes.
Unheated	264	15	293	5
Heated to 75° C. for ½ hour ..	264	15	219	35
Heated to 100° C. for ½ hour ..	55	45	192	15
Heated to 125° C. for ½ hour ..	7	45	174	35

In these two sets the original sample was identical, and the reversion, which has taken place while standing, is very marked. It agrees with the loss of utility of the *rab* process if it is done long before, illustrated on a previous page.

Another experiment which tends to make us suspect that there is something more than coincidence in the change in physical condition produced by heating, and the increased fertility that results from it is connected with the effect of oilcake as a manure for these rice seedbeds as a substitute for the *rab* process. Mr. Knight has shown (see page 154) that oilcakes are the very best substitutes for *rab* that we have, and that equally good, if not better, rice seedlings can be produced by their use than by burning the soil (*rab*). This is, in main part, doubtless to be attributed to the easily assimilable nitrogen which the oilcake provides. But this is not all. For though the same amount of nitrogen be added, the results are not identical with different oilcakes. One cake stands out as superior to all the others, namely, safflower cake (*Carthamus tinctorius*) derived from one of the most widely cultivated oilseeds in Western India. This superiority had already been manifested with other crops, notably with sugar-cane * and therefore was no surprise to us. But on testing its effect on the viscous matter in the soils with which we are dealing, and comparing with other oilcakes, the difference was at once seen to be very marked. The times taken for the soil and water mixture to become clear when shaken up immediately after mixing with the oilcake extract (in the manner already described) is shown in the following table :—

Treatment of Soil.	Time required for settling.		Weight of precipitable matter in 100 c.c. liquid.
	Hours.	Min.	Grammes.
Untreated ..	118	30	Not determined.
10 c.c. Safflower cake water extract	6	15	·009
10 c.c. Castor cake water extract	104	25	·009

* Vide *Various reports of Manjri Agricultural Station.*

Treatment of Soil.	Time required for settling.		Weight of precipitable matter in 100 c.c. liquid.
	Hours.	Min.	Grammes
10 c.c. Niger* cake water extract	114	10	·010
10 c.c. Nim† cake water extract	138	10	·012

(In all these cases the soil was shaken with chloroformed water to avoid any chance of the result being affected by the growth of organisms.)

This result is clear : an almost immediate precipitation is effected with the safflower cake extract, while little effect is produced with the other three cakes.

Repeated tests always gave similar results, but we have been so far unable to account for the specific action of the safflower cake extract. It was at first suspected to be due to some extra acidity which it might possess. Determinations of the acidity of these cake extracts (using phenolphthalein as indicator), however, gave the following results, calculating on the basis of the potash required to neutralise 10 c.c. extract as used above.

Cake.	Acidity in 10 c.c. extract. Weight of KOH required to neutralise.
	Grammes.
Safflower cake ..	·0196
Castor cake ..	·0024
Niger cake ..	·0148
Nim cake ..	·0232

It was evident, therefore, that acidity was not the cause of the great precipitating capacity of safflower cake extract. Following this, it was suggested that it was possibly due to the presence of a large amount of precipitable proteids in the extract, and determinations were, therefore, made of the amount of such proteids in the extracts in question. The proteids were precipitated by means of

* *Guizotia abyssinica.*
† *Melia indica.*

copper hydrate by the well known method, and the following results were obtained :—

Cake.	Proteids in 10 c.c. extract (Proteids = N × 6·25)
	Grammes.
Safflower cake ..	·0412
Castor cake ..	·0407
Niger cake ..	·0574
Nim cake ..	·0463

These figures afford no clue to the cause of the special capacity of safflower cake extract, and we have to leave the question for the moment but intend to return to it again at the first convenient opportunity.

But it remains clear that safflower cake has a specific action on the physical condition of the soil, that this leads to a state which is apparently similar to that produced by heat, and that the use of this cake is more effective than those cakes which have not this specific action. This may be a coincidence, but it is certainly very suggestive.

Can we produce a similar effect on the physical condition of the soil to that produced by heat by other means where no question of increased fertilisation can enter into the question? We are not certain how far this is possible, but the use of gypsum appeared to afford the most promising material. This is known to precipitate the viscous matter* in soil quite easily, and so cause a rapid deposit of soil shaken up with water. It is moreover a perfectly neutral salt, and is free from organic matter and nitrogen,—and hence, on the face of it would appear to have (for a soil containing ample available lime) little more than its physical effect.

To ascertain the amount of gypsum required to have a physical effect comparable with that produced by heating, 50 grammes of soil (unheated) were shaken up with water to which varying quan-

* We are using this method of expression throughout this paper rather than the more convenient term "flocculate," because the latter commits us to a particular view of the nature of the process.

tities of saturated gypsum solution had been added, the whole being made up to 250 c.c., side by side with a sample of the same soil previously heated to 125° C., shaken with pure water. The quantity of suspended matter in the liquid half way down the cylinder was then determined after 1 hour, 2 hours, and 24 hours in each case. The results were as follows :—

Soil Treatment.	Weight suspended matter per 100 c.c.		
	After 1 hour.	After 2 hours	After 24 hours.
	Grammes.	Grammes.	Grammes.
Heated to 125° C. for ½ hour	·155	·106	·020
·055gms. Gypsum per 100 gms. soil	·104	·096	·030
·027gms. Gypsum per 100 gms. soil	·300	·128	·040
·011gms. Gypsum per 100 gms. soil	·607	·215	·060

A second experiment gave very similar results, and so it was evident that while the precipitation by gypsum and by heat were not in every sense comparable, the amount of ·055 grammes of gypsum per 100 grammes of soil most closely represented the condition of things prevailing in a heated soil.

A culture experiment in cylinders, as before described, was therefore set out with this quantity of gypsum, and various multiples thereof were mixed with the top inch of the soil, this being the amount which was usually heated in our experiments. This corresponded with the addition of 3·75 grammes of gypsum to each cylinder, and the series was therefore as follows :—

Nos.	1 & 2	.. Unheated soil.
,,	3 & 4	.. 15 grammes of gypsum per cylinder.
,,	5 & 6	.. 7½ ,, ,, ,, ,, ,,
,,	7 & 8	.. 3¾ ,, ,, ,, ,, ,,
,,	9 & 10	.. 2 ,, ,, ,, ,, ,,
,,	11 & 12	.. Soil heated to 125° C. for ½ hour immediately before the experiment.

Duplicates were, therefore, grown in each case, but unfortunately Nos. 8 and 10 were lost owing to attack by insects, and in No. 2 one side of the cylinder was much more luxuriant than the remainder, probably owing to a bird dropping, and hence had to be

neglected. Omitting these results, the weights of (100) plants pulled up after growing for six weeks were as follows :—

Nos.	Treatment.	Weight. a	Weight. b	Average.
		grammes.	grammes.	grammes.
1 & 2 :	Untreated	5·46	..	(5·46)
3 & 4 :	15 grammes Gypsum per cylinder ..	6·36	6·12	6·24
5 & 6 :	7½ „ „ „ „ ..	6·09	6·15	6·12
7 & 8 :	3¾ „ „ „ „ ..	6·11	..	(6·11)
9 & 10 :	2 „ „ „ „ ..	6·12	..	(6·12)
11 & 12 :	Heated to 125° C. for ½ hour	8·75	8·32	8·53

The observations recorded during the growth of the plants were generally in accordance with these figures. The heated soil was always far better than any of the other cylinders. On the other hand, the untreated soil always (except at the very beginning) gave the worst looking plants. Taking these figures, and calculating the increase in the dry weight of plants in each pair as a percentage on the yield from the untreated soil, we have as follows :—

	Percentage increase in yield.
15 grammes of gypsum per cylinder	14 per cent.
7½ „ „ „	14 „
3¾ „ „ „	12 „
2 „ „ „	12 „
Heated to 125° C. for half hour	56 „

It is evident, therefore, that while the gypsum has given an increased yield, yet it can only give one quarter the effect given by simple heating to 125°C. for half an hour. The other striking point is that the increase of yield given by the gypsum is absolutely constant whatever quantity is applied. As much, or very nearly as much effect is produced by the smallest quantity added as by an amount seven and-a-half times greater. This rather tends to confirm the view that its physical effect is its principal, if not its only effect, in the present instance.

Whatever be the cause of these results, they are evidently effective in the growth of the plants and not in the germination of the seeds. All the seeds germinated almost equally

rapidly in all cases as the following sets of observations will show :—

Nos.	Treatment.	Number of Plants (per cent.) above ground.								
		4 days after sowing.			5 days after sowing.			6 days after sowing.		
		(1) %	(2) %	Aver. %	(1) %	(2) %	Aver. %	(1) %	(2) %	Aver. %
1 & 2	Untreated ..	13	5	9	73	63	68	81	79	80
3 & 4	15 grammes gypsum ..	22	10	16	75	72	73	82	78	80
5 & 6	7½ grammes gypsum ..	20	17	18	75	72	73	81	74	77
7 & 8	3¾ grammes gypsum ..	15	19	17	73	76	74	79	80	79
9 & 10	2 grammes gypsum ..	16	13	14	62	74	68	77	80	78
11 & 12	Heated to 125° C. for half hour ..	14	20	17	68	73	70	78	80	79

We may now put together a few provisional conclusions with regard to the question of the change in physical condition in soil produced by heating, and the part this change takes in the increase in fertility of the land as a result :—

(1) The heating of soil to an extent corresponding to that which occurs in the *rab* process materially changes the physical condition of the soil, in that a large part of the viscous sticky "clay" substance is brought into a condition in which it will not remain suspended in water.

(2) This effect is a very passing one, the mere keeping of the air-dry soil for six weeks being sufficient to materially reduce it, while it has disappeared after three months.

(3) The power to precipitate soil in this way is shared by the oilcake which is most effective as a *rab* substitute (safflower cake), and by no other among the cakes at our disposal.

(4) A material like gypsum which has a similar precipitating effect gives an increase in yield about one quarter the amount produced by heating the soil. Further addition of gypsum beyond the amount required to precipitate the viscous matter in the soil to the extent done by the heating process, gives no further increase in yield.

These must be recognised as very provisional and very preliminary conclusions. The matter is under further investigation, and it is hoped that the matter may be carried a stage further in the near future.

It seems clear, however, that while we have now traced one of the active causes in the benefit which soil heating (and hence the *rab* process) produces, this cause must still only be reckoned as a secondary one, though not one which can be neglected. It remains, however, to discuss the influence of heating on the biological character of the soil. Our experiments in this direction have not yet taken us very far, but they are, at least, suggestive.

The investigations of Russell* some years ago on the oxygen absorbed by moistened soils left us with a method by which one could estimate with some accuracy the total activity of the aerobic life of the soil. It consisted essentially in leaving the moistened soil in a confined space with air, with provision for the absorption of any carbon dioxide which might be evolved, and measuring the amount of oxygen utilised, simply by the decrease in volume of the air contained in the flask in which the experiment was conducted.

It appeared at once that this method afforded an opportunity to ascertain easily at any moment the activity of the aerobic life in the soils we were examining, and so it was used with only slight modification in our experiments. Ten grammes of soil was taken in every case, and the volume of oxygen absorbed corrected to 0° C. and 760 mm. pressure.

The first effect of heating is, as Russell has already shown for English soils, to very considerably diminish the oxygen absorbed by the soil, and this diminution is fairly proportional to the extent of heating. All our soils were heated dry in an air oven. The first results were as follows :—

* Journal of Agricultural Science, Vol. I.

Experiment I.—Absorption of Oxygen by freshly heated soil.
June 2nd to June 25th, 1908.

Treatment of soil.	Volume of Oxygen absorbed by 10 grammes soil.					
	June 5th.	June 8th.	June 13th	June 17th.	June 22nd.	June 25th.
	c. mm.	c. mm.	c. mm.	c. mm.	c. mm.	c. mm.
Untreated (1) ..	233·1	244·2	321·9	366·3	399·6	388·5
(2) ..	211·2	220·8	297·6	336·0	374·4	365·8
Heated to 75° C. for one hour (1) ..	184·0	230·0	287·5	333·5	379·5	379·5
(2) ..	170·4	191·7	244·9	298·2	319·5	319·5
Heated to 100° C. for one hour (1) ..	140·2	140·2	215·0	233·7	271·1	271·1
(2) ..	119·3	119·3	212·0	230·4	267·1	267·1

The next experiment shows the same thing, if anything, more clearly.

Experiment II.—Absorption of Oxygen by freshly heated soil.
March 21st to April 26th, 1909.

Treatment of soil.	Volume of Oxygen absorbed by 10 grammes of soil.											
	March.			April.								
	24	27	30	2	5	8	11	14	17	20	23	26
	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
Untreated (1)	37·0	52·2	62·2	65·4	90·1	100	100	100	100	100	100	100
(2)	27·9	37·8	44·5	57·9	65·5	70·1	70·1	70·1	70·1	70·1	70·1	70·1
Heated to 100° C. for half hour (1)	20·4	30·1	35·4	35·4	40·4	40·4	40·4	40·4	40·4	40·4	40·4	40·4
(2)	22·3	22·2	20·1	20·1	25·6	30·2	30·2	30·2	30·2	30·2	30·2	30·2
Heated to 100° C. for one hour (1)	10·6	30·4	36·7	36·7	25·9	20·3	20·3	20·3	20·3	20.3	20·3	20·3
(2)	11·1	31·3	30·3	30·3	35·6	29·1	29·1	29·1	29·1	29·1	29·1	29·1
Heated to 125° C. for half hour (1)	12·0	15·5	25·6	25·6	17·8	17·7	17·7	17·7	17·7	17·7	17·7	17·7
(2)	0·00	0·00	10·2	15·6	14·5	14·5	14·5	16·6	20·2	20·2	20·2	20·2

The immediate effect of heating the soil is, therefore, to very largely reduce the aerobic life of the soil, though with a dry heat up to a temperature of 125° C. for half an hour it is never wholly destroyed.

If this heated soil is then kept air-dry in a corked bottle, it quickly recovers all and more than it has lost. Then when the soil examined in Experiment II was kept for seven weeks, the result was altogether different from that already recorded. The actual figures were as follows :—

Experiment III.—Absorption of Oxygen by soil heated seven weeks before experiment. May 10th to June 9th, 1909.

Treatment of soil.	Volume of Oxygen absorbed by 10 grammes of soil.								
	May 13	May 14	May 16	May 18	May 21	May 25	May 28	June 2	June 6
Untreated(1)	49·5	59·4	79·2	89·1	95·4	95·4	95·4	95·4	95·4
(2)	46·5	64·15	82·6	91·8	96·7	96·7	96·7	96·7	96·7
Heated to 100° C. for half hour(1)	40·1	60·5	80·6	90·9	100·8	100·8	100·8	100·86	100·86
(2)	40·5	60·5	80·8	90·9	101·2	101·2	101·2	101·20	100·20
Heated to 100° C. for one hour (1)	43·1	64·1	86·2	107·2	118·1	118·1	118·1	118·15	118·15
(2)	54·8	65·8	87·7	109·7	119·9	119·9	119·9	119·93	119·93
Heated to 125° C. for half hour(1)	75·8	88·5	114·8	140·2	140·2	146·4	146·4	152·34	152·34
(2)	60·3	70·3	100·5	130·6	130·6	139·7	139·7	145·95	145·95

These figures are of great interest. Whereas, when freshly heated, the soil heated to 125° C. hardly absorbs any oxygen, now after seven weeks the absorption exceeds that of any of the other soils. The soil heated to 100° C. for one hour stands next, and the other two were almost identical. The unheated soil absorbs rapidly at first, and then after ten days nothing further is absorbed by this soil.

If we carry out a further examination of the above soils, kept air-dry in a bottle till July 1st, or just over fourteen weeks, the effect of the heating has almost wholly disappeared and the results tend to be somewhat irregular. The following are the actual figures :—

Experiment IV.—Absorption of Oxygen by soil heated fourteen weeks before experiment. July 1st to July 25th, 1909.

Treatment of soil.		Volume of Oxygen absorbed by 10 grammes of soil.											
		July 4	July 5	July 6	July 7	July 10	July 13	July 14	July 15	July 18	July 20	July 23	July 25
		c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
Untreated	(1)	2	19·3	19·8	19·8	25·4	25·4	25·4	37·8	37·8	44·2	44·2	44·2
	(2)	8·45	10·9	20·1	20·1	29·3	29·3	29·3	35·8	35·8	45·1	45·1	45·1

Treatment of soil.		Volume of Oxygen absorbed by 10 grammes of soil.											
		July 4	July 5	July 6	July 7	July 10	July 13	July 14	July 15	July 18	July 20	July 23	July 25
		c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
Heated to 100° C. for half hour	(1)	4·65	24·5	40·9	40·9	45·4	55·6	55·6	55·6	66·1	71·4	71·4	71·4
	(2)	..	22·9	30·7	30·7	25·9	36·4	36·4	26·4	37·0	47·9	47·9	47·9
Heated to 100° C. for one hour	(1)	3·07	19·2	36·2	36·2	36·2	46·2	46·2	56·2	61·2	66·4	66·4	66·4
	(2)	3·5	20·6	37·0	37·0	37·0	37·0	37·0	47·1	52·2	62·4	62·4	62·4
Heated to 125° C. for half hour	(1)	3·5	20·6	29·5	29·5	29·5	32·3	44·5	44·5	49·5	53·8	53·8	53·8
	(2)	3·07	19·6	26·2	26·2	30·3	31·3	40·1	40·1	46·6	52·9	52·9	52·9

The aerobic life of the soil is still a little more active in the case where the heating was greatest, and least active where the soil had not been heated, but the difference has now very largely disappeared. This is, of course, in accordance with what we have found by culture experiments and in connection with the physical condition of the soil. The effect of the heating has largely though not entirely disappeared after three months.

A doubt arose at one time as to whether the absorption of oxygen was due to living agency. On treatment of any of the above soils, however, with water saturated with thymol instead of with pure water, no absorption took place, proving of course that the absorption of oxygen was conditioned by something destroyed by thymol,—in other words, by soil organisms.

It is evident, therefore, that the fertility of the soil is not dependent on the presence in large numbers of soil organisms at the moment when the plants are growing. For, at the time when the heated soil is in its most fertile condition, that is to say, immediately after it has been heated, the number and activity of the aerobic soil organisms is at its lowest point. As they increase during the keeping of the soil, so does the beneficial effect of the heating tend to disappear.

It is a matter of some interest, though we recognise that the method we used is open to objection, that we have not succeeded in detecting the presence of nitrifying power in the soil with which

most of these studies have been conducted. In order to test this point, flasks were taken containing 25 c.c. of sterilised culture medium, and then 5 gms. soil was added to each of them and kept at the temperature of the laboratory for two weeks, and for five weeks. At the end of each of these periods the nitrates in the whole contents of the flasks were determined. No nitrates were found in any of the cases, whether the soil used was unheated, or had been heated to 100° C. for half an hour, to 100° C. for an hour or to 125° C. for half an hour.

IV. Conclusions and Recommendations.

What then are the general conclusions to which the whole of the foregoing results lead ? It must be recognised that the present is a first study, and being this, we may consider the results as provisional. Particularly, the short section which deals with the biological effect of heating the soil under the conditions of rice culture in Western India must be regarded as only an opening of the subject. But subject to revision in the light of future investigation we may summarise the conclusions which we have so far reached as follows :—

1. The *rab* process, as used in the preparation of the seedbed for rice in Western India, owes its efficiency to two causes—the heating of the soil, and the ash and other manurial material left on the land. The actually increased returns in the improved seedlings obtained, vary very much, but normally the weight of the seedlings obtained is from one and a half times to twice as great as without the treatment.

2. Of this increase nearly sixty per cent. is due to the effect of heating, and the balance to the ash and other materials added.

3. Taking the effect of heating alone, with which the present study deals, it may be said that during ordinary burning with cowdung *rab*, the temperature at $\frac{1}{2}$ inch deep does not go beyond 110° C. and at 1 inch deep not beyond 85° C. The whole heating process does not last longer than $1\frac{1}{2}$ to 2 hours.

4. The result of heating the soil to 75° C. was only very slight at any time.

5. At temperatures higher than this, a very great increase in fertility resulted up to a maximum at about 125° C. Beyond this point (at 150° C.), the effect appears to be less.

6. The greatest effect is produced when the heating is conducted immediately before the sowing of the crop. If the soil is heated six weeks before the rice is sown, the effect is a little less; while if conducted three months before sowing, comparatively little effect is obtained.

7. This action of heating affects the growth of the plants. On speed of germination it has no beneficial effect,—apparently sometimes slightly retarding the process. This retarding does not appear to be due to the production of a deleterious substance.

8. The heating of the soils in question does lead to the production of a considerably increased supply of assimilable mineral plant foods in the soil, and of soluble organic matter. Very little of the benefit of heating can be due to this cause, because very little effect was produced when growing rice plants were treated with extracts of such heated soil.

9. The heating of the soils in question also materially changes the physical condition of the soil, in that a large part of the viscous, sticky, "clay" substance is brought into a condition in which it will not remain suspended in water. This effect is a very passing one, the mere keeping of the air-dry soil for six weeks being sufficient to materially reduce it, while it has disappeared after three months.

10. The power to precipitate soil in the way described under (9) is shared by the oilcake which is most effective as a *rab* substitute (safflower cake) and by no other among the cakes at our disposal. A material like gypsum which has a similar precipitating effect gives an increase in yield of about one-quarter the amount produced by heating the soil. Further addition of gypsum beyond the quantity required to precipitate the viscous matter to the extent done by the heating process, gives no further increase in yield.

11. The change in the physical condition of the soil by the action of heat is one of the causes, though only secondaary cause of the beneficial effect of the *rab* process.

12. The heating process has the effect of destroying a very large proportion of the active aerobic life of the soil, but even when kept in an air-dry condition the organisms rapidly again multiply, till, six weeks after the heating, the aerobic activity is far greater than in the unheated sample. The difference disappears on further keeping of the soil.

13. The fertility of the soil is not dependent on the presence of large numbers of soil organisms at the moment when the plants are growing. The fertility of a heated soil is greatest when the aerobic organisms present are fewest.

Such are the provisional conclusions to which our experiments directly lead. It only remains to consider what bearing they have on the actual practical methods of preparing the rice seedbed in Western India. Considered from this point of view, the principal conclusion we have so far been able to reach, is that no method not involving a greater actual out-of-pocket expenditure, seems likely to yield the results which are obtained with the combined application of heat and of wood ashes to the soil which is given in the *rab* process.

This being the case, it would seem that attention should be largely concentrated on obtaining the application of these by a less wasteful method than the ordinary burning of *rab*. Our experiments clearly indicate that if the heating effect is obtained, combined with the application of the wood ashes, it matters little how it is brought about.

Now the *rab* process is obviously wasteful of heat and of fuel, if our explanation of the object to be attained is the correct one. No one can doubt this who has watched closely the actual practice in vogue, and we feel confident that the quantity of fuel—that is to say, of cowdung, of branches, and of the other materials employed—could be reduced to, at most, one-quarter of the amount at present used if, instead of its being spread over the surface of the soil, the

latter could be burnt in heaps. At first sight this would seem difficult if not impossible, but we feel this is a superficial view. The area to be burnt is small, not amounting to more than five *gunthas* per acre of rice : the soil to be heated, consists only of the surface layer to one inch deep. Thus to plant one acre of rice would require the heaping up and burning of a comparatively small amount of soil.

The chief difficulties in this seem to be as to how best it can be carried out, and to ascertain this should be the next direction that experimental work should take. It would not seem difficult to devise a reasonable method, requiring far less fuel and trouble in collecting fuel than is submitted to now. That soil, especially a heavy sticky, clayey soil like that in these regions, can be so burnt in heaps is proved by the former common practice of so burning it in Europe, and by the practice in the fen districts of England at the present day. And in this direction the solving of the difficulties, both of the cultivators and of those who are anxious to prevent the damage to the forests and trees in the rice tracts of the Deccan and Konkan, seems most probably to lie.

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